

Early Satellite Tracking Results from SLR2000

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Design Goals for SLR2000

- Unmanned, 24/7 tracking to satellites up to 22,000 km range
- Free of optical, electrical, and chemical hazards
- ~ 1 cm (RMS) single shot ranging (or better)
- 1 mm normal points for LAGEOS
- Mean time between failures: > 4 months
- Automated two-way communication with central processor
- Ability to operate for days without communication
- Reduce replication and operations costs through standardization, COTS technology, and automation

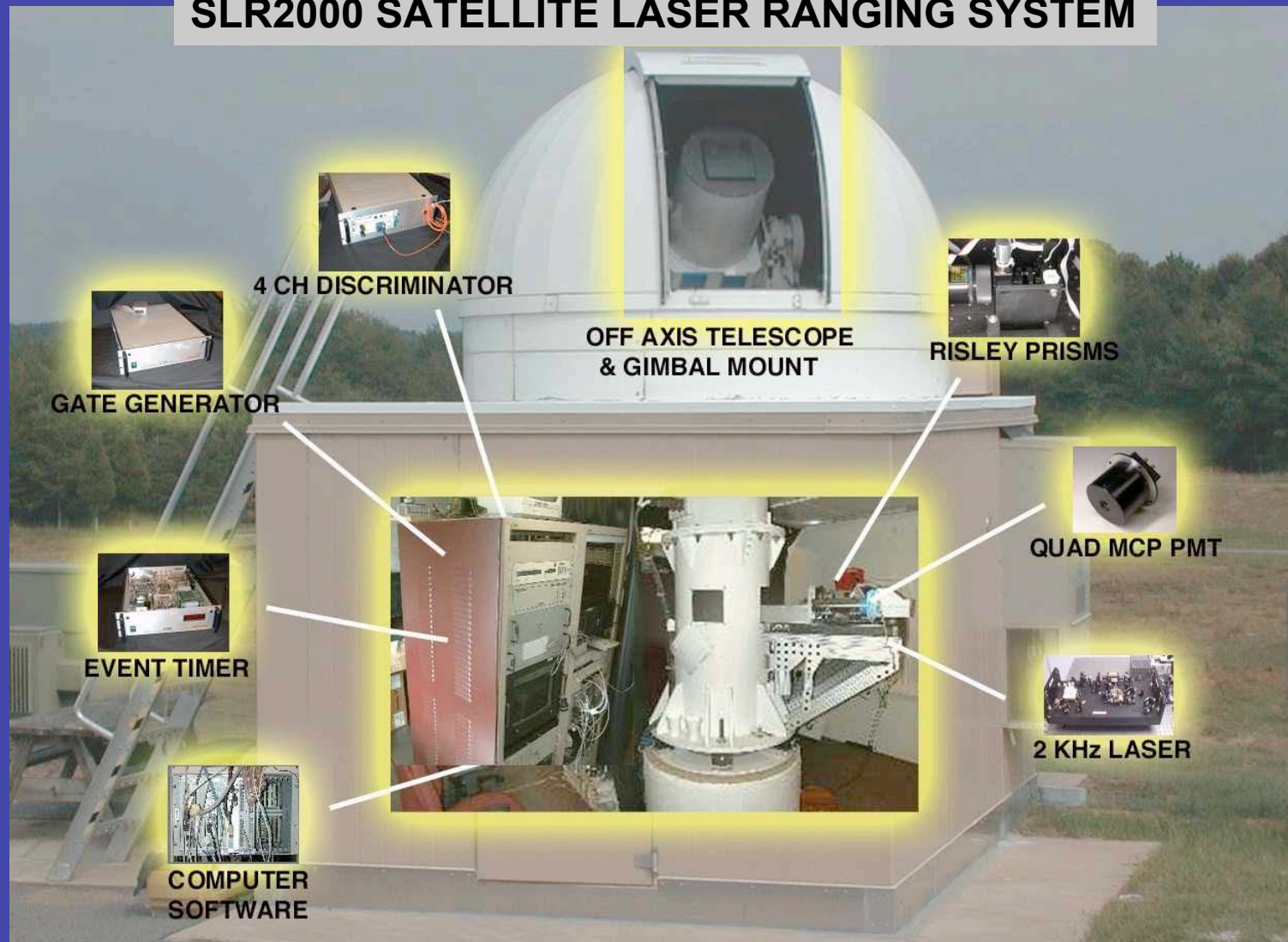


System Characteristics

- **Laser: Nd:YAG**
 - Fire rate: 2 kHz
 - Pulse energy: 135 uJoules/pulse at exit aperture
 - Beamwidth: Variable: 10 to 40 arcseconds (FWHM)
 - Point ahead: Risley prism pair (0-11 arcseconds)
- **Detector:** Photek quadrant MCP PMT
 - Gain: 3.E+6
 - QE: 13% at 532 nm
 - Image area: 6mm diameter quadrant centered
- **Receiver:** 4 independent channels
 - Field of view: 10 to 40 arcseconds
 - Discriminator: Phillips Scientific 708
 - TIU: HTSI 1.5 psec resolution Event Timer
- **T/R switch:** Passive (Polarization insensitive)
- **Tracking mount:** Xybion Corp Ax/EI gimbal
 - Command Rate: 50 Hertz
 - Tracking error: ~ 1 arcsecond RMS
- **Telescope:** OSC 40 cm off-axis



SLR2000 SATELLITE LASER RANGING SYSTEM





LICENSE NO. _____ CLASSIFICATION _____ EXPIRATION DATE _____ EXPIRATION MONTH _____ EXPIRATION YEAR _____		CONTRACT NO. _____ FIRST RECEIPT OF PAYMENT _____ DATE _____ AMOUNT _____ PAYEE'S NAME _____ ADDRESS _____ CITY _____ STATE _____ ZIP _____ PHONE _____ FAX _____ E-MAIL _____ COMMENTS _____ DATE _____ BY _____ TITLE _____	
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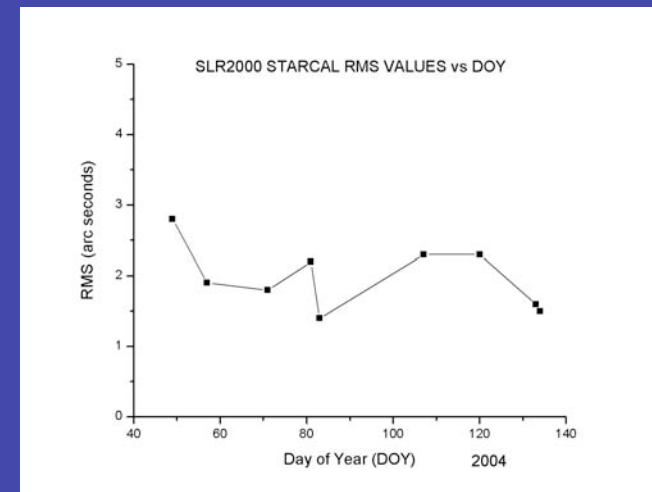
Current Progress toward Meeting System Goals

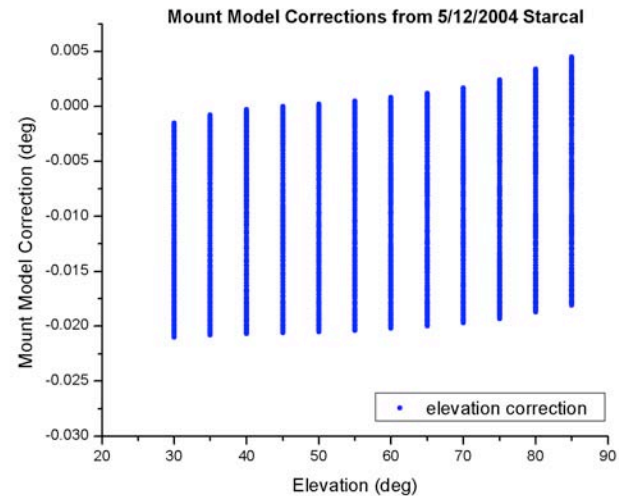
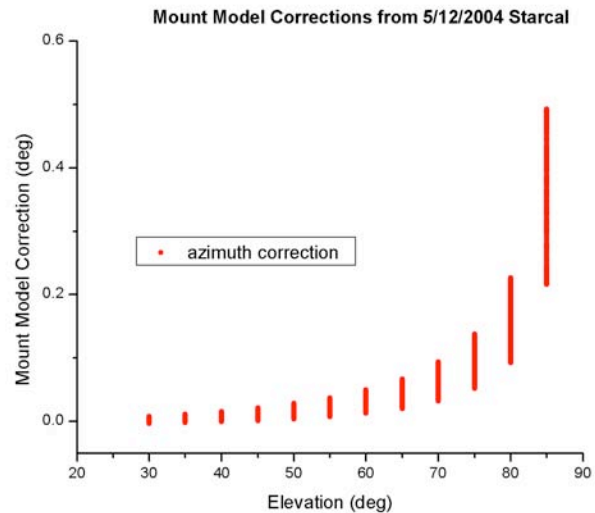
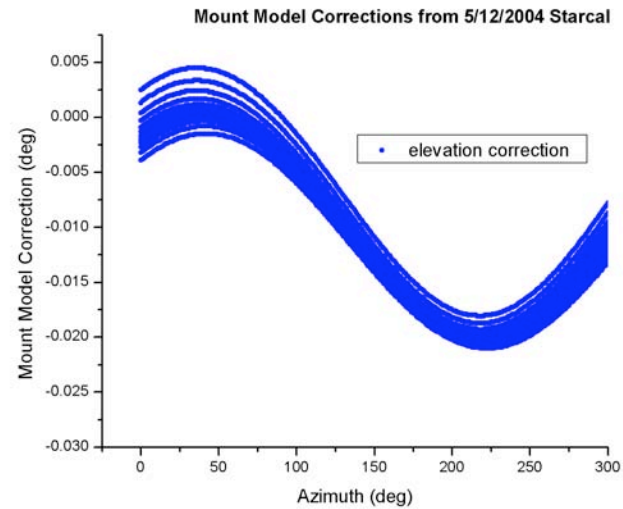
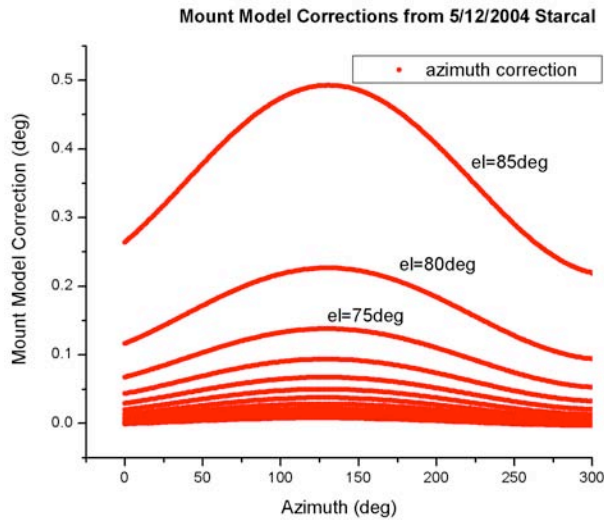
- Star calibrations are routinely performed and completely automated.
- Ground ranging is also routinely performed and is semi - automated.
- System can track LEO satellites under operator control.



Star Calibrations

- System pointing is at the few arc second level and appears very stable.
- Current mount model (22 terms) provides a good fit (~ 2 arc seconds) for elevations from ~ 10 degrees to 90 degrees.
- Once the dome is opened, star calibrations are completely automated and take approximately 30 minutes to gather data from 66 stars. Solution is calculated by least-squares fit of the data to the 22 term trigonometric model.
- CCD camera (EDC 1000m) image is 242×242 pixels over ~ 2 arc minute field of view. Five images are summed (and background removed) to allow processing software to register images down to 5th magnitude. Software determines image centroid and calculates pointing biases from centroid location.

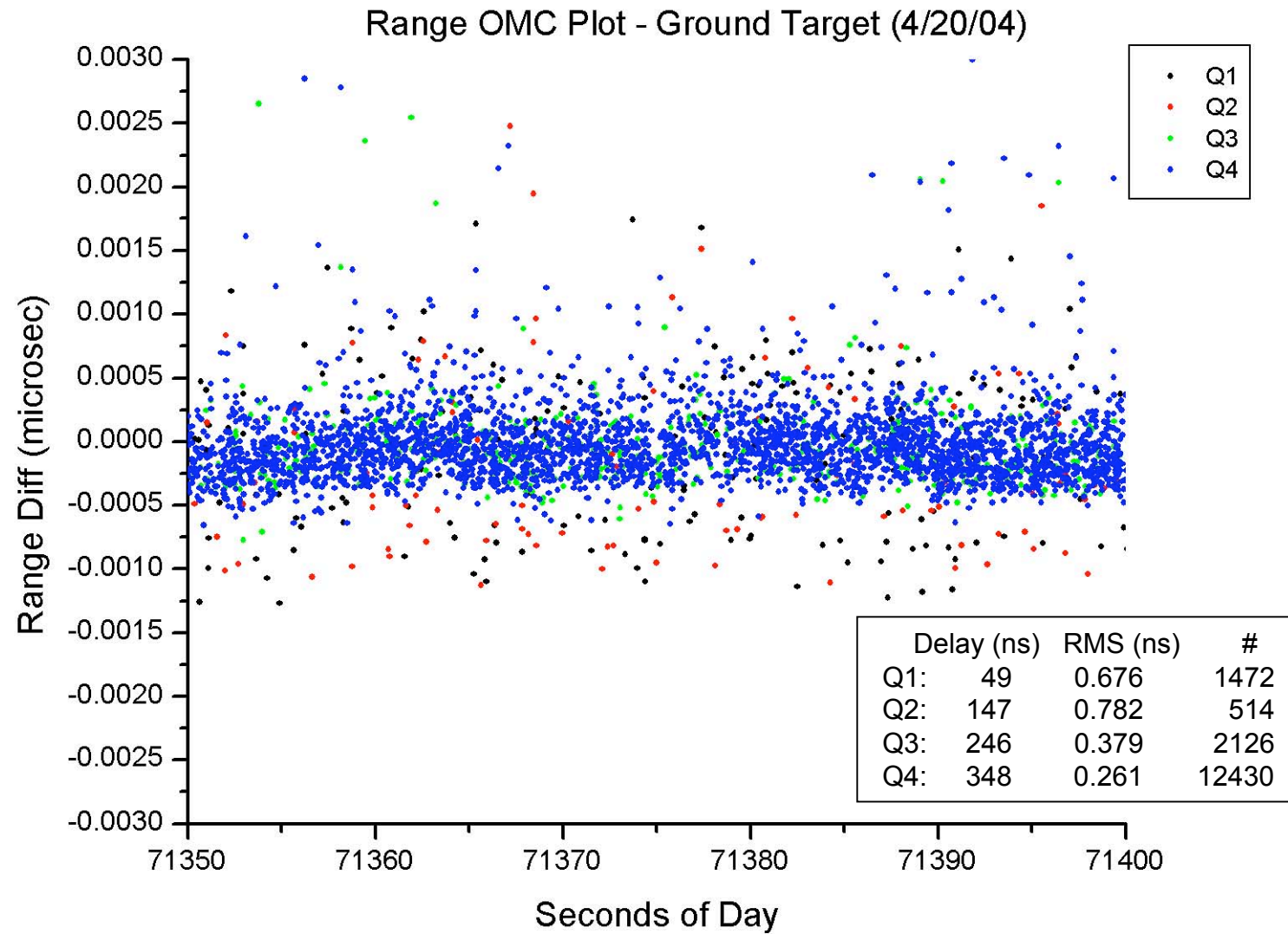




Ground Calibrations

- System Delay measurements are taken for all four quadrants.
- Successful real-time signal processing of ground target range data is now routine.
- Automated angular search and acquire works well on ground target (uses signal processing to determine when target has been acquired).
- RMS is high. May be reduced by upgrade of discriminator to a constant fraction Canberra CFD no. 454.
- High signal return rate causes higher noise rate (beyond signal): still being investigated.
- Our next step is to use the quadrant information to optimize the pointing.





Visual Satellite Tracks

- Initial testing of system pointing (Fall 2003 and early 2004) was done using sunlit AJISAI and TOPEX passes.
- Images were captured using the star CCD camera.
- Telescope is currently pointed ahead of satellite - so image should move in the CCD field of view as the difference between the point-ahead of the telescope and the point-behind of the sunlight from the satellite.
- Complicating the image motion is the Coude path rotation.
- Conclusion of tests was that system open-loop pointing was good.
- These tests are also good for checking our calculation of point-ahead minus point-behind.



Point-Ahead Equations

- Telescope points along \vec{R}_B ,
Laser beam must point along \vec{R}_A :

$$\cos(\rho) = \vec{R}_A \cdot \vec{R}_B / |\vec{R}_A| \cdot |\vec{R}_B|$$

$$\cos(\beta) = \vec{R}_0 \cdot (\vec{R}_A - \vec{R}_B) / (|\vec{R}_0| \cdot |\vec{R}_A - \vec{R}_B|)$$

which equivalently is:

$$\rho = \sqrt{(\Delta Az)^2 \cdot \cos(El)^2 + (\Delta El)^2}$$

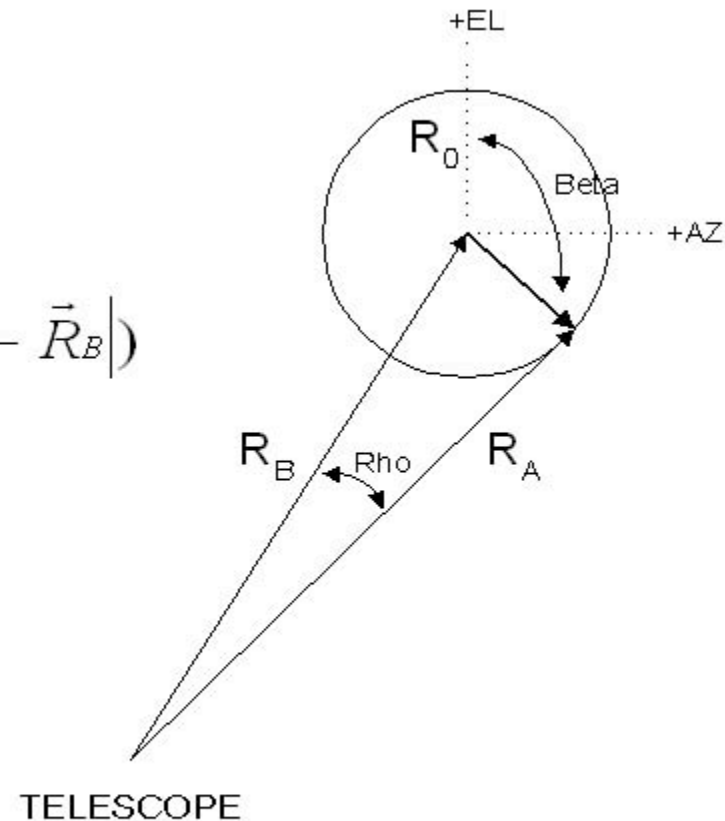
$$\beta = \tan^{-1}(\Delta Az \cdot \cos(El) / \Delta El)$$

where:

ρ = Magnitude Angle (0 - 11 arcsec).

β = Orientation Angle (0-360 deg).

ΔAz , ΔEl = difference between point ahead and behind command angles.



Visual AJSAI images: 3/12/2004 (GMT 072/23:40)



23:49:06 EL= 37°

Images intensify, rotate
and move away from
FOV center as elevation
increases.

FOV center is (120,120).

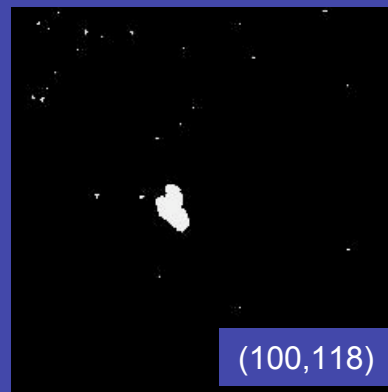
Centroid location is shown
on each image.



23:52:58 EL= 75°



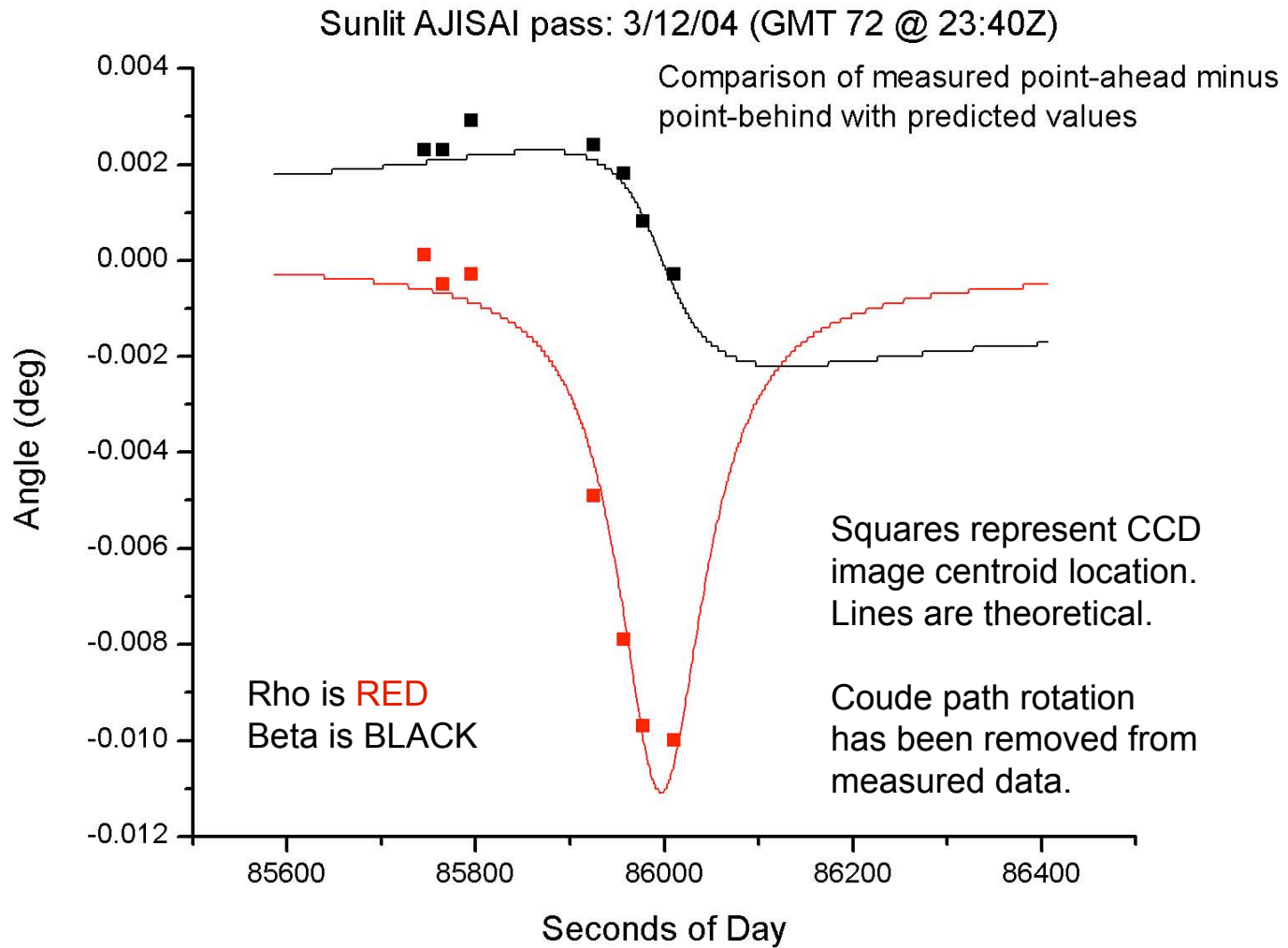
23:49:26 EL= 40°



23:52:06 EL= 68°



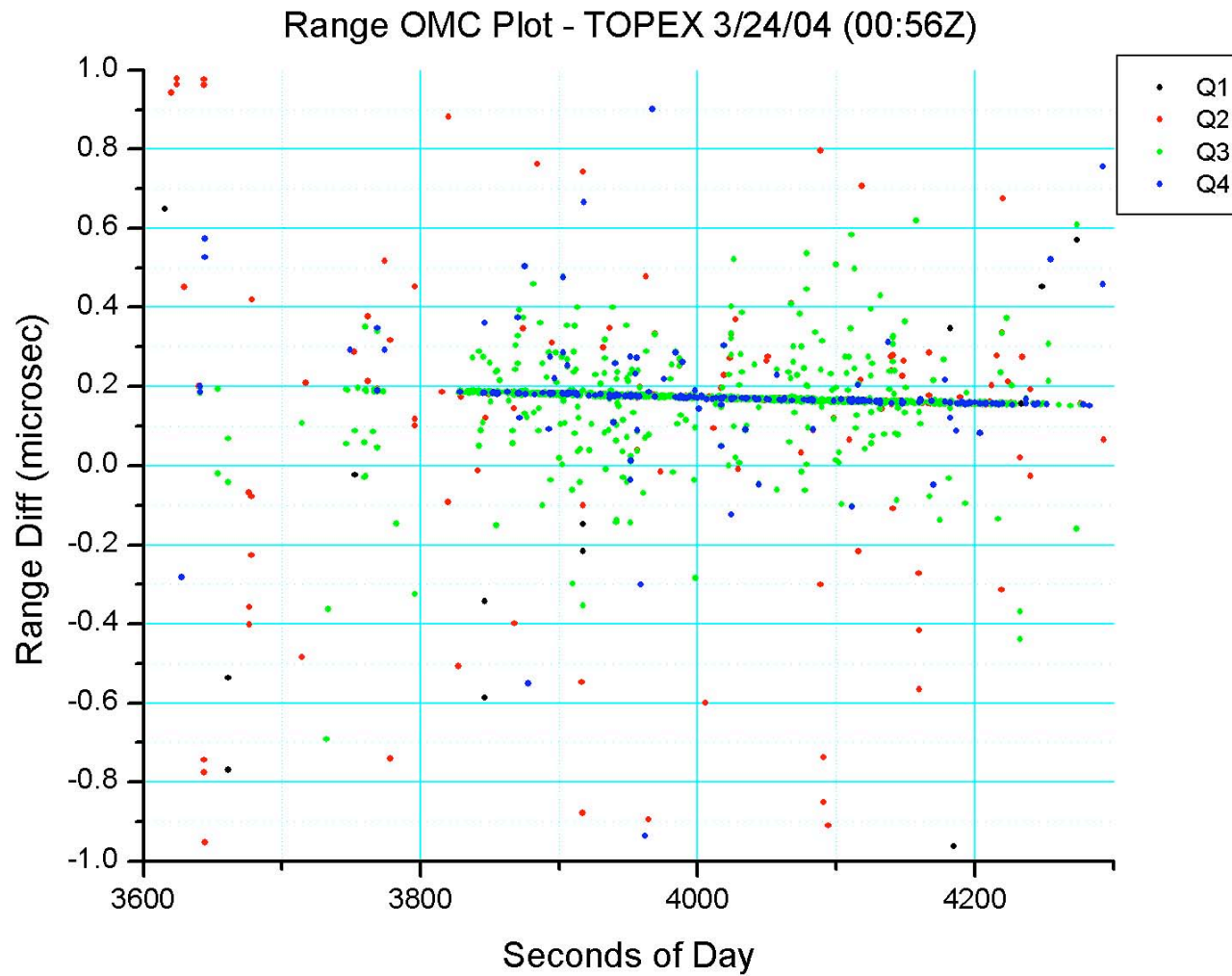
23:52:26 EL= 73°



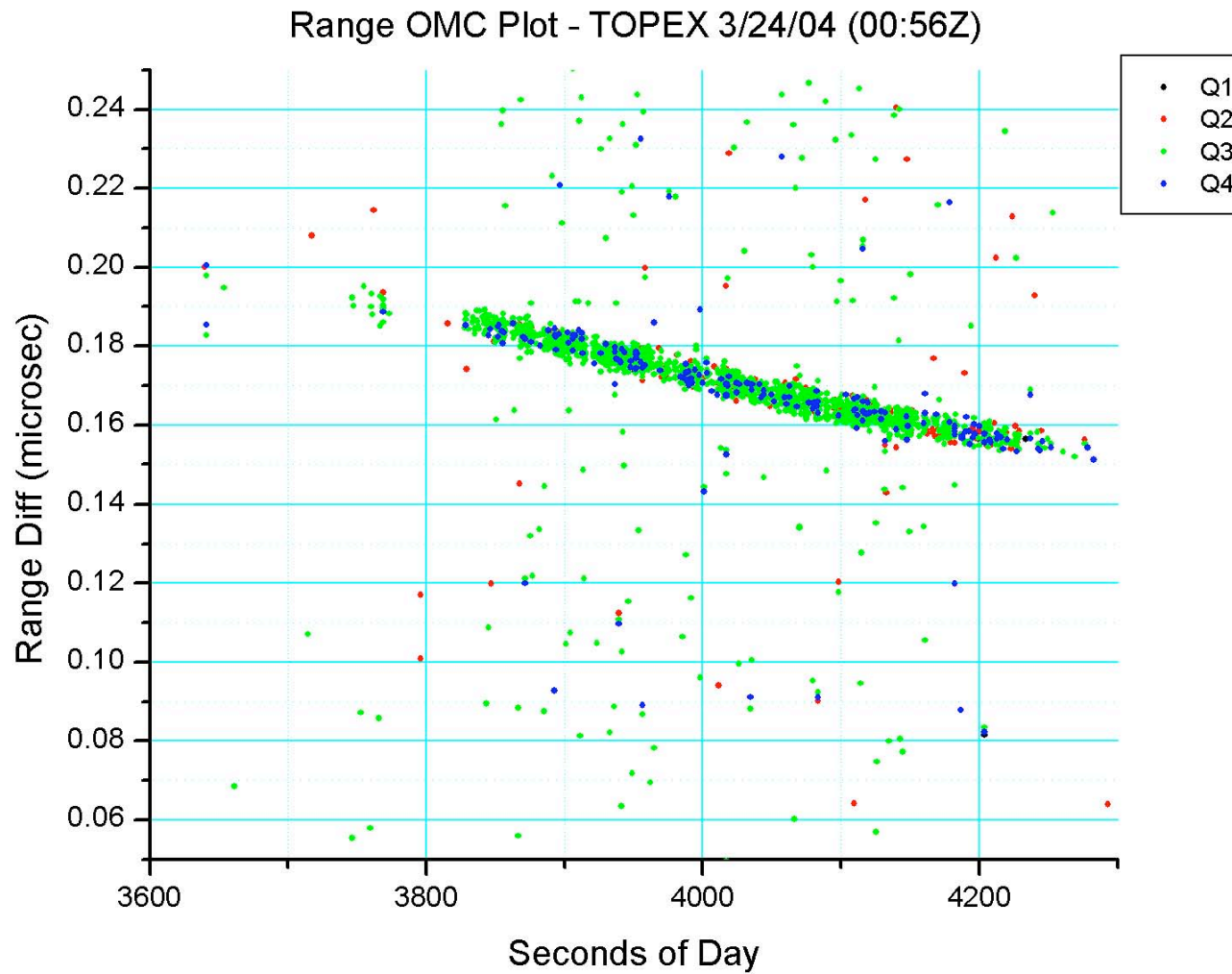
Satellite Tracking

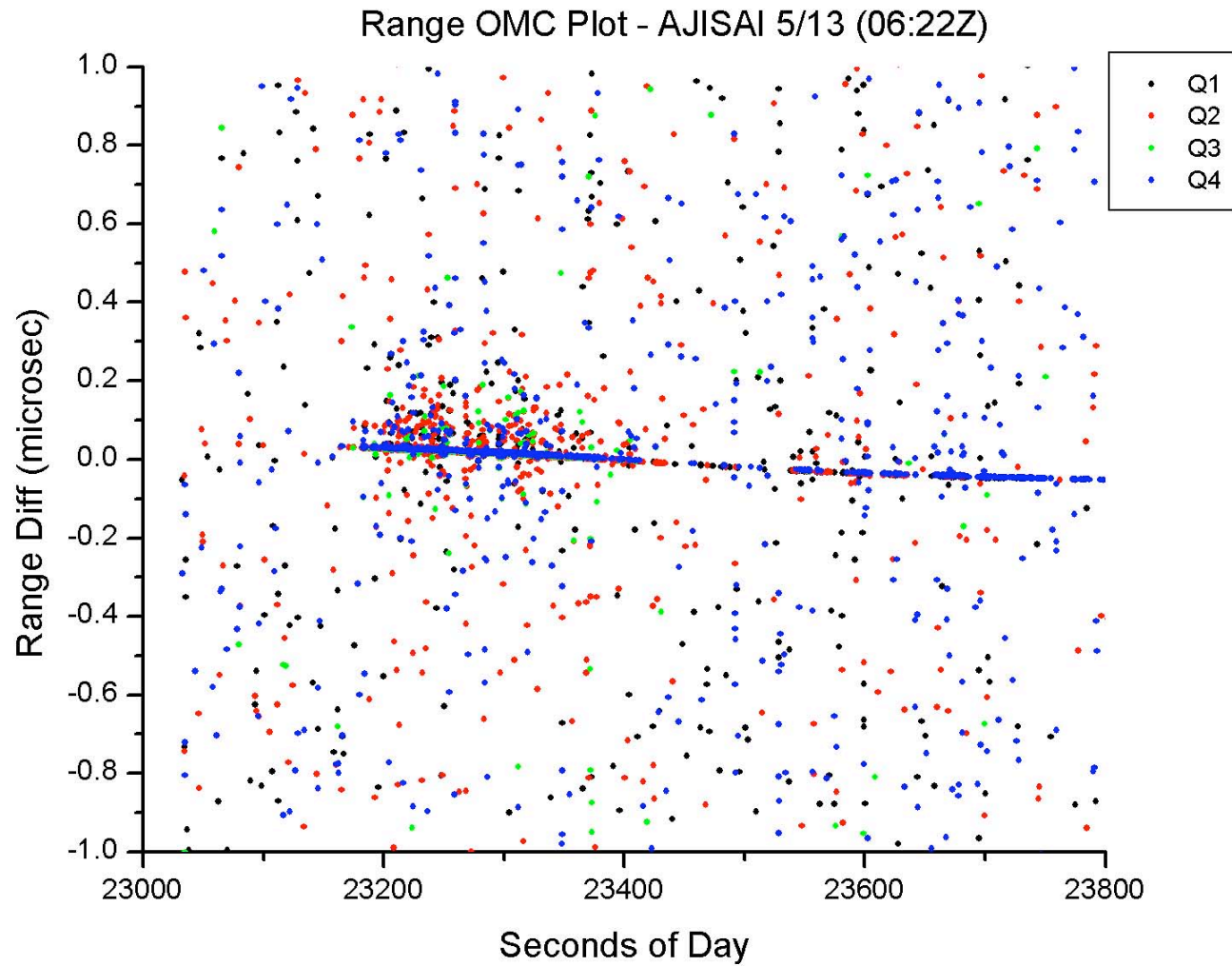
- We have tracked portions from ~ dozen satellite passes – all LEO with relatively high lidar cross-sections, and all under operator control.
- Final laser (300 microJoule output) is ~ 1 year behind. We are currently operating with a laser whose output energy is ~60 microJoules. Return signal strength is low even with the 10 arcsecond beam divergence.
- Open-loop pointing of predictions is extremely good. Predictions are in a form similar to that proposed by the Prediction Format Study Group.
- Signal processing works on satellite tracks when return rate is high enough.
- Telescope is currently pointed ahead of satellite (no Risley Prism point-ahead has yet been implemented). Detector is opened to 40 arcseconds.



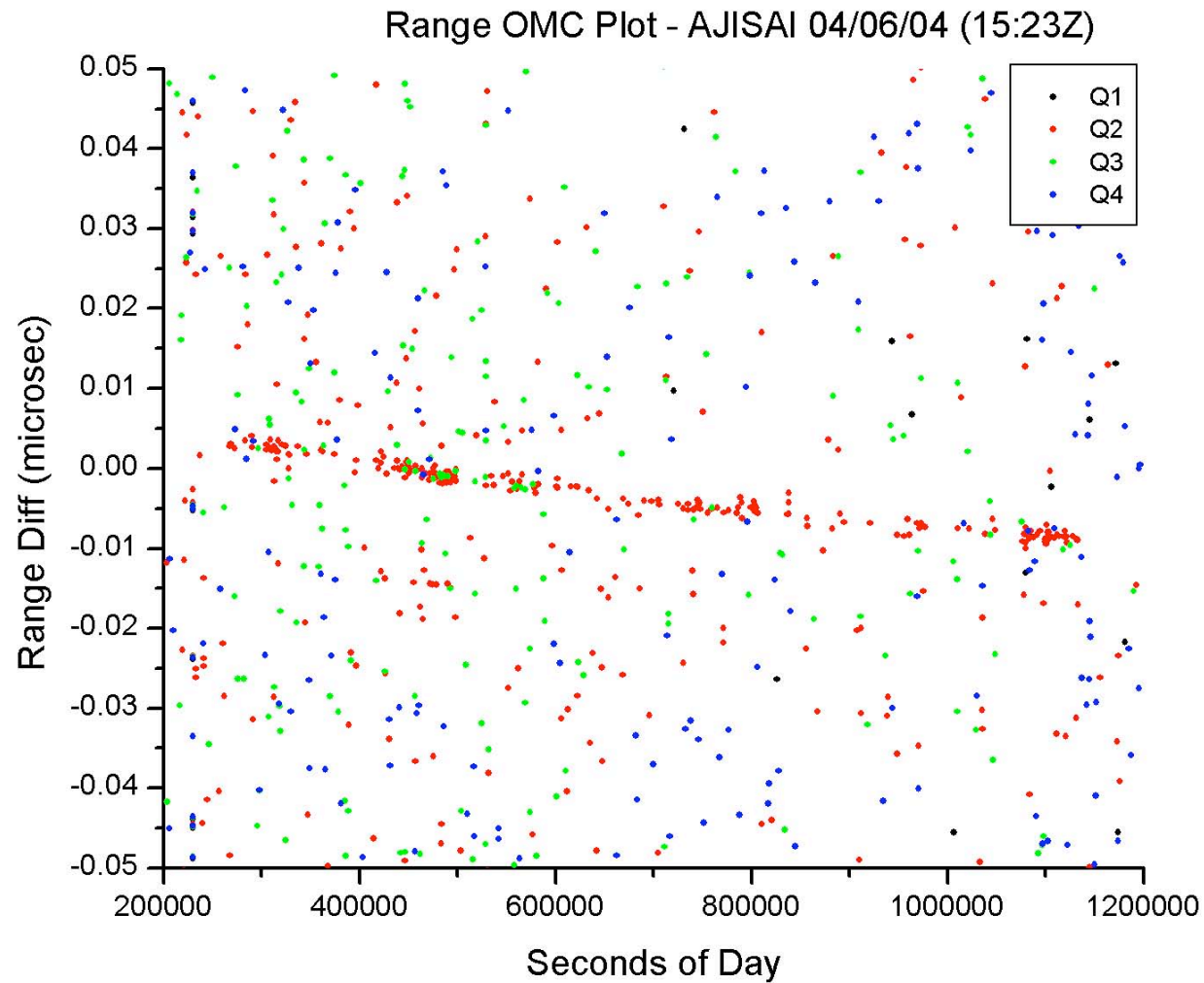


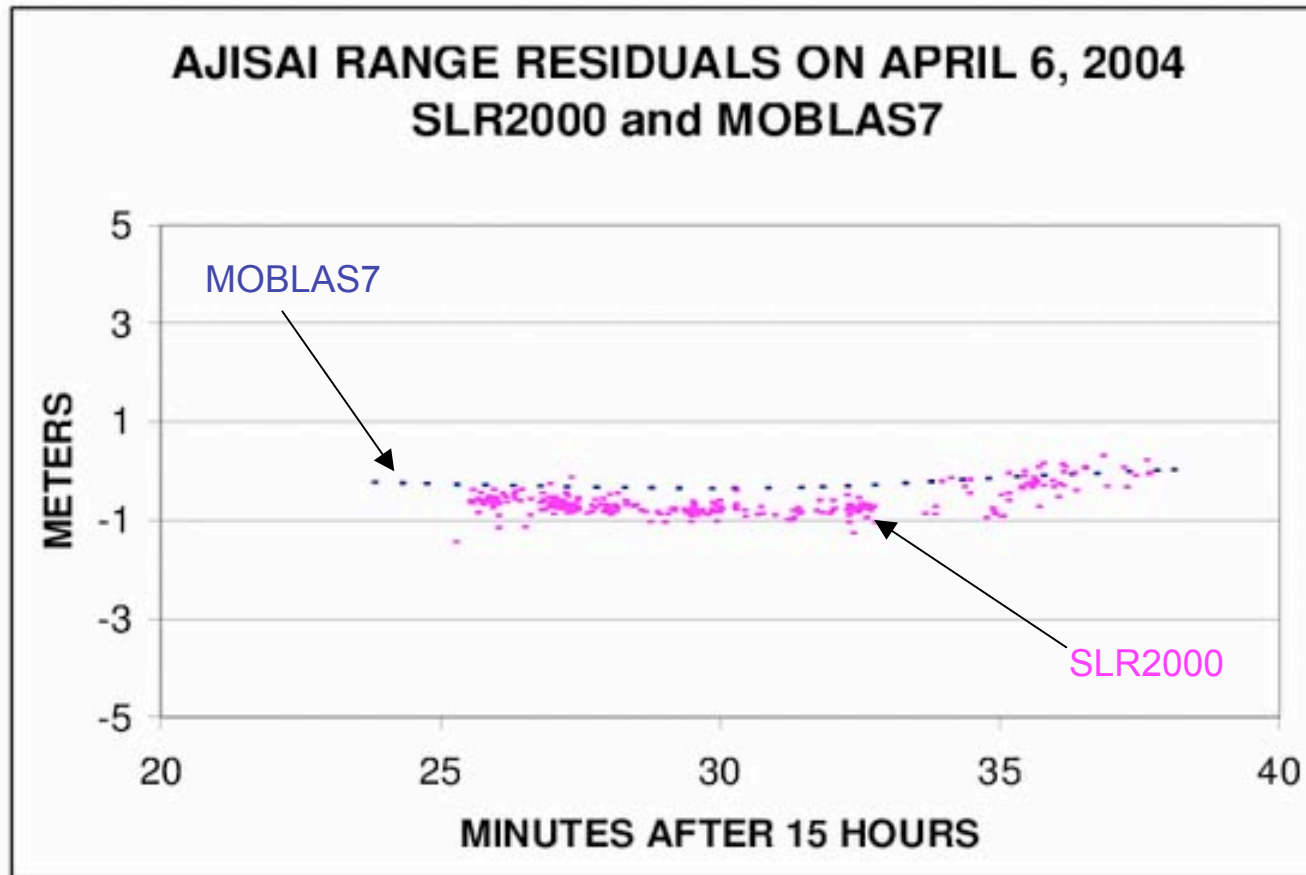
Zoom into previous plot





Daylight pass collocated with MOBILAS-7





Where do we go from here?

- Laser must be completed by Q-Peak or upgraded in-house.
- Discriminator to be upgraded constant fraction Canberra model no. 454.
- Receiver optics replaced will include: appropriate daylight / twilight bandpass filters, adjustable iris field of view stop, and more angular sensitive focusing elements to optimize quadrant detector closed loop operation.
- Range data problems (high noise in high signal environment) must be resolved.
- Transmitter Point-Ahead will be implemented. The telescope will be pointed behind (so receiver can be centered on returns) and the laser pointing will be offset using Risley Prisms to steer the beam ahead to where the satellite will be when the light reaches it.
- Once the Point-Ahead has been implemented, closed-loop tracking using the quadrant detector can be completed.

GOAL: completion of these tasks this year



Summary

- The SLR2000 prototype is now tracking satellites but there is a lot to do before the system is considered operational (even in a semi-automated state).
- We expect to have a system that can perform semi-automated tracking of LAGEOS and ETALON within the next year.
- Real-time determination of signal processing parameters and selection of satellite tracks based upon the sky map should occur sometime in CY2005.
- There do not appear to be any insurmountable technical issues – we just need to work out the remaining problems.
- Funding is the real question at this point.

